



ICI Optical Data Storage Tape

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1. Introduction to flexible optical media

Optical data storage tape is now a commercial reality. The world's first successful development of a digital optical tape system is complete. This is based on the *Creo 1003* optical tape recorder with *ICI 1012* write-once optical tape media. Several other optical tape drive development programs are underway, including one using the *IBM 3480* style cartridge at LaserTape Systems.

In order to understand the significance and potential of this step change in recording technology, it is useful to review the historical progress of optical storage. This has been slow to encroach on magnetic storage, and has not made any serious dent on the world's mountains of paper and microfilm. Some of the reasons for this are:

- The long time needed for applications developers, systems integrators and end users to take advantage of the potential storage capacity.
- Access time and data transfer rate have traditionally been too slow for high-performance applications.
- Optical disk media has been expensive compared with magnetic tape.

As one of the world's major international chemical companies, ICI's strategy in response to these concerns has been to concentrate its efforts on flexible optical media; in particular optical tape.



2. Manufacturing achievements

Flexible optical media offers many benefits in terms of manufacture; for a given capital investment, continuous, web-coating techniques produce more square meters of media than batch coating. The coated layers consist of a backcoat on the non-active side; on the active side there is a subbing layer, then reflector, dye/polymer and transparent protective overcoat. All these layers have been tailored for ease of manufacture, and specific functional characteristics.

3. Media characteristics

The media can contribute to high system performance over a very wide range of capacities, depending on the drive design and media format. In addition to low cost/MegaByte, the media offers the archivability and indelibility that is vital for many storage applications. Thus, the media permits the development of systems that provide a unique set of features:

- **Low on-line cost/MB:** 10¢ to 40¢/MB depending on the format.
- **Low media cost/MB:** $\frac{1}{2}$ ¢ to 1¢/MB at first, falling with time.
- **High performance in access time:** the low track spacing and high longitudinal speed of fixed head optical tape drives allows search rates between 2 GB/s and 20 GB/s. This compares very favorably with helical scan magnetic drives.
- **High data rate:** a single laser channel can achieve 4 MB/s with 60 mW on the media surface, and this can readily be increased with the use of multiple lasers.
- **High volumetric efficiency:** flexible optical media offers efficiencies a factor of 10 higher than advanced helical magnetic recording.



- **Indelible media:** the original information cannot be erased and altered.
- **Unlimited read cycles:** non-contact recording means that the data will survive in excess of 30,000,000 read cycles. The number of tape wind cycles is very high.
- **Long media lifetime:** the use of chemically stable materials has allowed us to predict a lifetime in excess of 15 years.

4. Media lifetime

Optical media based on organic, dye/polymer materials is well-known for its chemical stability. An unfortunate consequence of this is the difficulty in predicting a lifetime. Several accelerated aging techniques are in common usage: steady-state elevated temperature and humidity with Arrhenius extrapolation; elevated levels of temperature plus corrosive gases (the "Battelle" test); and chemical stability investigations.

We have used all of these extensively, both to attempt to predict an absolute lifetime limit, and in comparisons with magnetic tapes: iron oxide, cobalt modified iron oxide, chromium dioxide and metal particle formulations. We have also compared our media with rigid optical disks, including stability to uv light.

The Arrhenius test is performed at various constant conditions of elevated temperature and humidity (Ref. 1). The test assumes the following relationship, where failure is dominated by one chemical process with a given activation energy: $1/\text{time} = A\{e^{-E/RT}\}$. Our initial criteria for failure was a change in absolute reflectivity of 5% (Fig. 2) or a drop-off in the Carrier-to-Noise Ratio (CNR) by 3 dB (Fig. 3). This level of failure was not detected for any of the samples. A better way of detecting failure is to measure the raw BER on a drive; we are now doing this on the Creo drive.



To generate an Arrhenius estimate (Fig. 1), we looked for any deviation from the starting values that was significant compared with the measurement accuracy. There was no measurable change for the sample at 55 °C. The sample at 95 °C was well above the glass transition temperature of the PET base film, and so was badly warped, and this led to inaccurate reflectivity measurements and prevented us from doing a CNR measurement. The Arrhenius graph slope gives an activation energy of 1.12 eV. This implies that a sample kept at conditions of 20 °C and 60 %RH would survive for 393 years. A comparison with other forms of optical media is shown in Table 1.

We have used two UV stability tests. The *Blue Wool Test* was developed for dyes used in the clothing industry, and has now been formalized as British Standard BS1006. It assesses light fastness on a scale of 1 (low) to 6 (high). ICI's media measures > 4 with the test still continuing. By comparison, the average textile dye measures < 4.

Another UV test was used by Sony to test their optical disk media (Ref. 2). This exposes a sample to 120 hours of UVA light at 45 °C and 60 %RH, and is equivalent to 70 days of sunshine. We saw 1% drop in reflectivity - a result similar to that for *Sony Century Media*.

We also compared our media to metal particle and metal oxide tapes, and examined, respectively, recording characteristics and chemical stability.

The metal particle tapes were stored under accelerated aging conditions, and the recording characteristics were assessed by looking for any changes in the magnetic properties. We bought two tapes; tape "A" is consumer R-DAT and tape "B" is 8 mm video, both were different major Japanese brands. The test method consisted of storing the tapes at a constant 60 °C and 80 %RH for 3 and 6 weeks, while keeping a Control tape at room conditions. The magnetic properties were then measured in a high saturation field VSM. This work was done for ICI by the Fulmer Research Company in England, and is summarized in Table 2. The signal strength dropped by up to 22% after 6 weeks.



We performed an analogous test on the ICI optical tape out to 9 weeks (Fig. 4). The signal strength was unchanged, and the CNR curves did not change within the measurement accuracy. In addition, we used a Time Interval Analyzer (TIA) to look for an increase in the intrinsic error rate by measuring a Geometric Error Rate (GER) on unwritten media, and looking for changes. The GER is directly proportional to the sum of the defective areas. Figure 5 displays this against the detector threshold level, normalized to unwritten media at 100%. Points below 100% are dark defects, and those above are light defects. ICI media darkens upon writing and a typical detector threshold level is 60%, so the GER increased by less than a factor of 2.

Temperature cycling tests can be used to test not only the chemical stability of the media, but also the mechanical integrity of the structure. It is not possible to infer a lifetime from cycling tests. We subjected the optical tape media to 20 temperature cycles defined by Figure 6. We again looked for changes in the signal characteristics. There was 1 or 2 dB drop in the CNR (Fig. 7), which is just greater than the measurement accuracy. The time interval results in Figure 8 showed a corresponding increase in the signal jitter (standard deviation) of 3 ns. The "(+/-)" refers to the signal's rising-to-falling half cycle, and "(-/+)" is the other half cycle.

A range of oxide magnetic tapes were stored under accelerated aging conditions, and any degradation was assessed by looking for any decomposition products. This work was also done by Fulmer Research. We tested three tapes; tape "C" is iron oxide instrumentation tape, tape "D" is cobalt modified iron oxide VHS consumer video tape, and tape "E" is chromium dioxide *IBM 3480* type data cartridge tape.

The test method was to store the tapes at a constant 60 °C and 80 %RH for 3 and 6 weeks, and keep a Control tape at room conditions. Standard solvent extraction techniques were used to look for decomposition products. One meter samples were immersed for two hours in a Soxhlet extraction by Delifrene; then soluble extract was weighed. This was followed by a further two hours in acetone and weighing the extract.



The results are presented in Table 3. The initial extract is a baseline, and the percentage increase above this is a measure of chemical decomposition in the binders. These results can be put into perspective through a paper by Bertram and Cuddihy (Ref. 3). This states that after aging, an increase in extract of 1.4 % by weight corresponds with a degradation in tape performance. When our results are compared with Bertram and Cuddihy's, there was very good agreement for the Tape "C".

We performed a similar chemical stability test on the optical tape. Again, the test method was to store at a constant 60 °C and 80 %RH, and also 80 °C and 80 %RH for 1, 2 and 3 weeks, and keep a Control tape at room conditions. We were unable to detect any decomposition products at a constant 60 °C and 80 %RH, which was why the test was repeated at the more severe conditions of 80 °C and 80 %RH.

We devised an extraction technique suitable to the solubility of the dye/polymer material. This involved immersing 500 cm² samples for 72 hours in a Soxhlet extraction by ethanol. Samples and extract were then weighed and analyzed by sensitive FTIR techniques. Using FTIR, we could detect binder degradation only at the harsher conditions of 80 °C and 80 %RH, and this for a minor component of the protective overcoat, not the recording layer. The quantities were too small to be weighed.

Another test we used is the *Battelle Class II* accelerated aging test, performed under contract at the Battelle Institute in Ohio. This test has been correlated to aging of materials in cities and other locations where combustion byproducts form a mix of corrosive gasses. A fully assembled open reel *ICI 1012* optical tape, without the protective sealed storage and shipping box was kept at a constant 23 °C and 70 %RH in a flowing mixed gas environment consisting of 10 ppb H₂S, 10 ppb Cl₂ and 200 ppb NO₂ for 30 days. This environment has been correlated to 15 years lifetime. We detected no damage in terms of corrosion, reflectivity or modulus.



5. Conclusion

Optical tape systems can offer a unique set of attributes to potential end-users. The use of chemically stable recording materials, indelible write-once technology, plus the advantages of non-contact reading and writing, yield a very robust and archival medium. Our lifetime studies have concentrated on measurement techniques and comparisons with magnetic technologies that are independent of the drive and read/write channel. The comparisons with magnetic tape technologies are favorable:

- No deterioration in optical recording characteristics after 9 weeks, 60 °C and 80 %RH.
- Metal particle magnetic formats show up to 22 % deterioration in magnetic capability after only 6 weeks.
- No binder hydrolysis in the optical tape recording layer after severe environmental exposure and extraction process.
- Minor hydrolysis present in the overcoat after 3 weeks at 80 °C and 80 %RH.
- Clear evidence of deterioration in magnetic oxide tapes under an industry standard hydrolysis test.

We plan to extend these studies to raise the lifetime prediction for *ICI 1012* optical tape from 15 to 30 years, and to characterize any changes in the raw BER through the read/write channel on the *Creo 1003* optical tape recorder.

References

1. A B Marchant, *Optical recording: a technical overview*, Addison-Wesley Publishing Company, pp 380-382, 1990.
2. Sony Publication *Recording Principle and Reliability Study of Sony Century Media*, Sony Corporation of America, Park Ridge, NJ, April 1988.
3. H N Bertram and E F Cuddihy, "Kinetics of the Humid Aging of Magnetic Recording Tape", *IEEE Trans Magn*, vol MAG-18, no 5, pp 993-999, Sept 1982.



Table 1

Company	Media Type	Test Method	Activation Energy in eV
Sony	Metal Alloy	BER	1.5
ICI	Dye/polymer	%R and CNR	1.12
OITDA*	Multi WORM	%R	1.0
Hitachi	12" WORM	BER	1.0
NEC	Magneto-optic	DER	0.97

*OITDA = Japanese Standard Committee for the Optical Data Disk

Table 2

Tape	Time	M _a % fall	M _r % fall	Sq % fall
"A"	Control	0	0	0
	3 weeks	10.64	11.30	0.74
	6 weeks	18.84	20.34	1.84
"B"	Control	0	0	0
	3 weeks	4.20	4.38	0.19
	6 weeks	22.35	22.31	-0.015

Table 3

Tape	Time	Total Extract in %	Increase in %
"C"	Control	1.20	0
	3 weeks	2.35	1.15
	6 weeks	3.49	2.29
"D"	Control	1.24	0
	3 weeks	1.45	0.21
	6 weeks	1.86	0.62
"E"	Control	1.53	0
	3 weeks	2.04	0.51
	6 weeks	2.55	1.02



Fig. 1

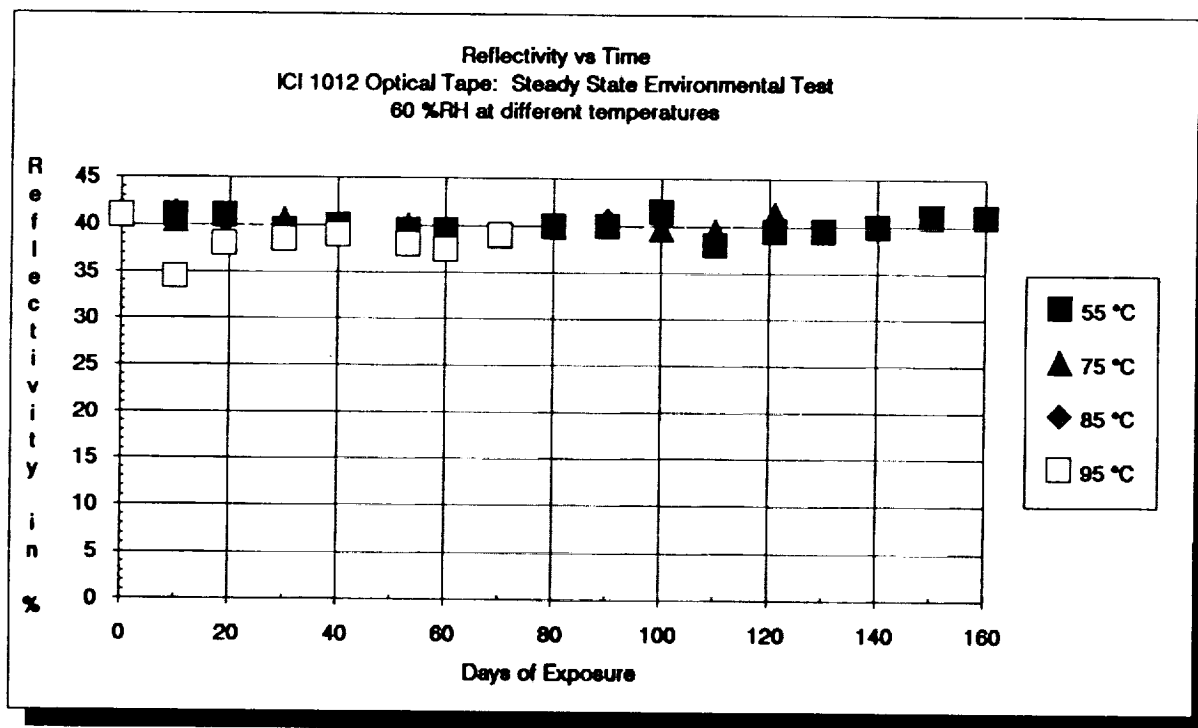
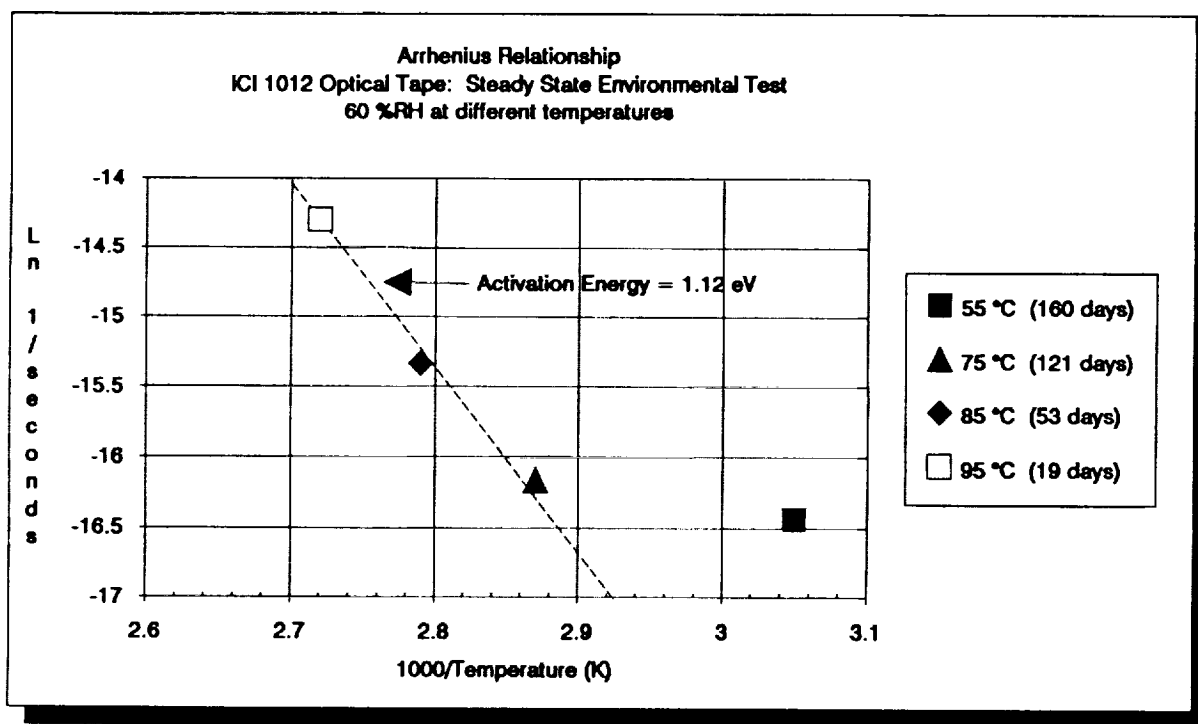




Fig. 3

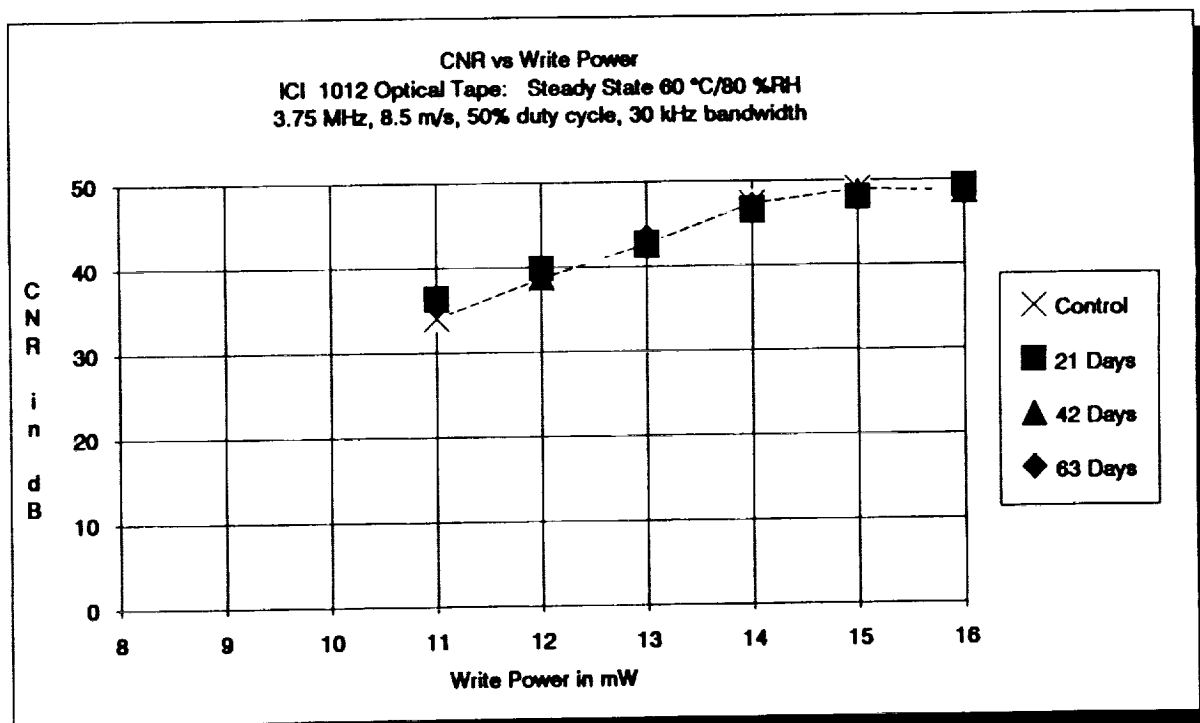
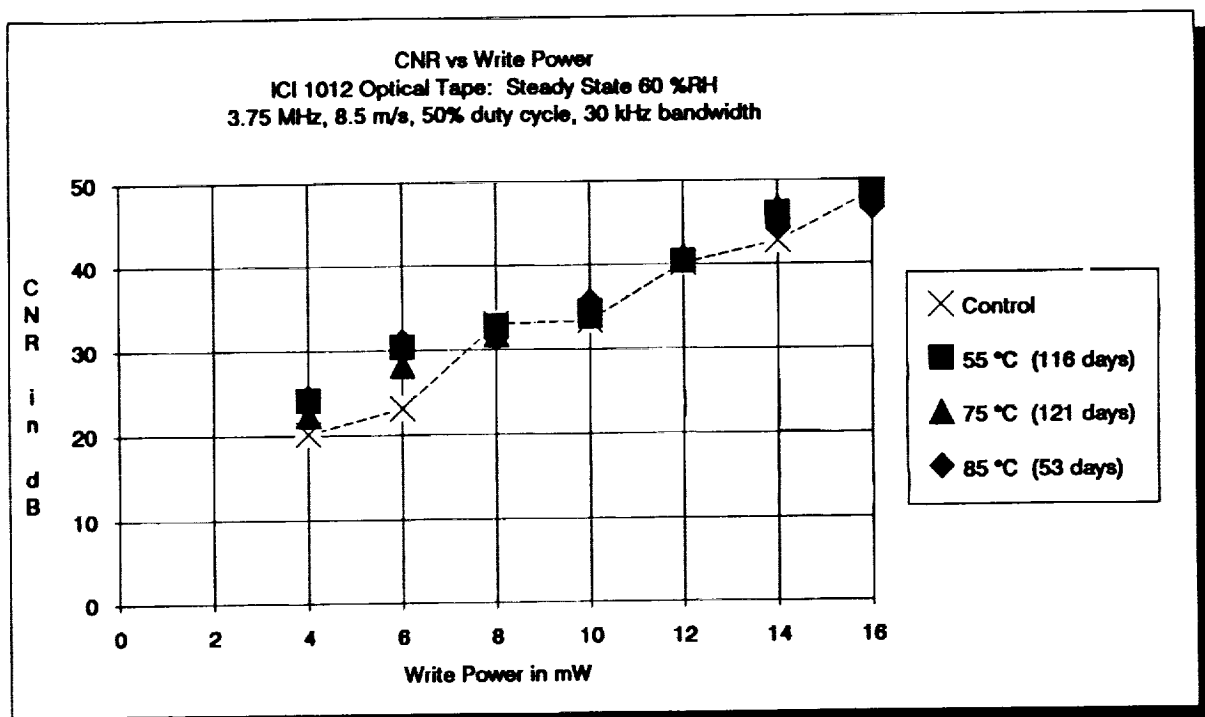




Fig. 5

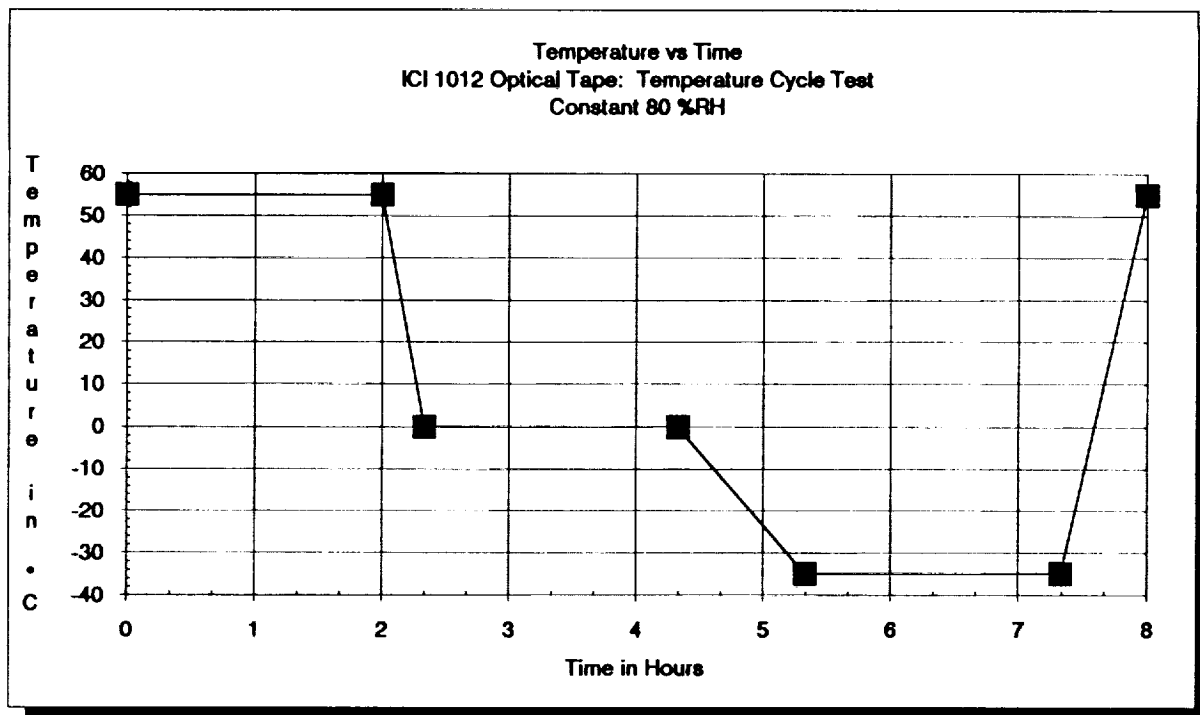
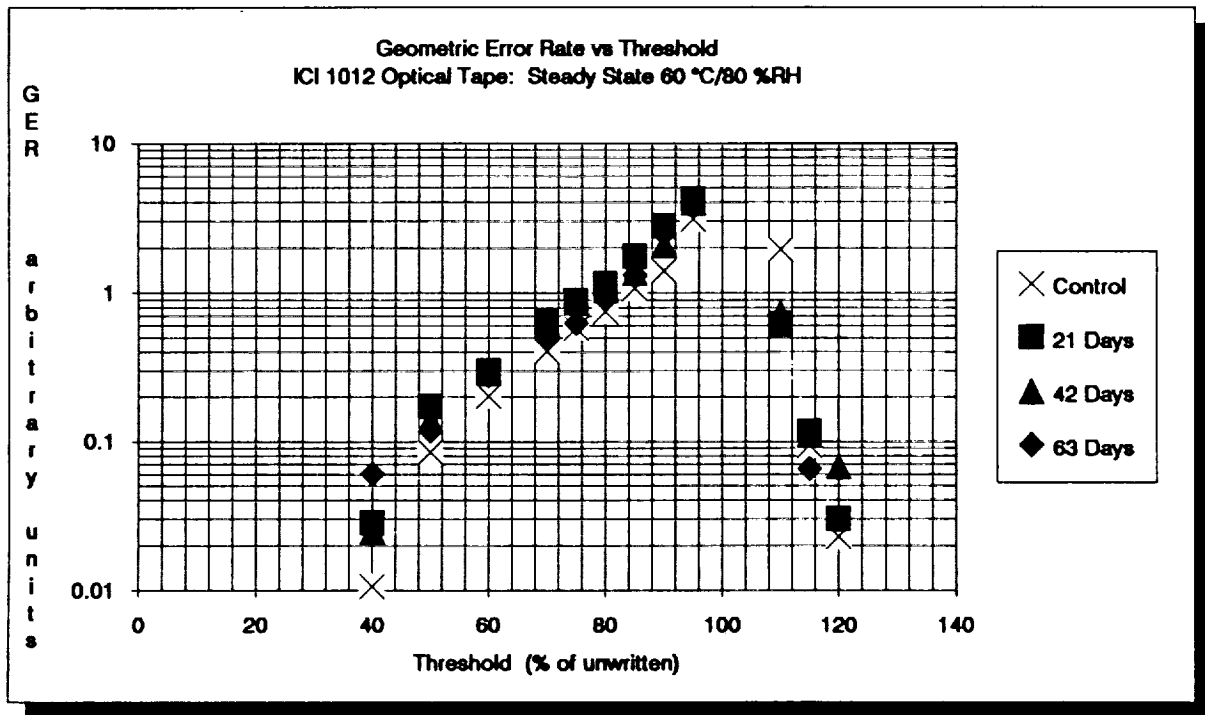




Fig. 7

